A New Approach to Assessing and Managing Micro-fisheries – A Case Study of the Victorian Western Zone Abalone Fishery (Genus *Haliotis).*

Jeremy D. Prince*, Harry Peeters**, Harry K. Gorfine***

* Biospherics P/L, PO Box 168, South Fremantle, WA 6162, Australia

**Western Zone Abalone Divers Association PO Box 5330, Geelong North, VIC 3215, Australia

*** Primary Industries Research Victoria, DPI Queenscliff Centre, PO Box 114, VIC 3225, Australia.

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Abstract

The need to manage and assess spatially complex fisheries like abalone fisheries at finer spatial scales poses challenges for industry, managers, compliance officers and researchers. Failure to address this challenge is implicated as a major course of fisheries declines generally and abalone fisheries in particular. This paper details a new approach being developed by the Victorian Western Zone Abalone Diver's Association which is based on the evaluation population fecundity on the basis of shell shape and appearance. The technique has been used as a form of rapid assessment by researchers, to educate and empower commercial divers individually and as a basis of a decision tree to structure reef assessment workshops. Supported by the responsible government agencies the technique has proved a means of forging far-sighted co-operative fine-scale behavior amongst divers in the zone which appears to be addressing underlying sustainability concerns.

Introduction

There is a growing realisation that many marine resources are not large uniform resources amenable to broad-acre assessment and management strategies (Hilborn et al. 2005). Instead many resources are composed of a mosaic of relatively independent and variable sub-stocks that effectively comprise micro-fisheries within the boundaries of spatially crude assessment and management scales (Prince 2005). With broad scale regional management fishing pressure is applied differentially across the component micro-stocks. Fishing pressure is focussed on the most attractive areas according to a sliding scale of preferences evaluated primarily on the basis of proximity, accessibility, safety and profitability. The most attractive during any period are inevitably fished sequentially into localized recruitment collapses and even localized extinction causing a long term loss of overall productivity.

Gulland (1969) stressed that at the basis of all fishery assessment models was the assumption that the unit of stock being fished had a level of homogeneity and mixing such that it comprised a uniform population that it could respond uniformly to fishing. The challenge is to reduce the scale at which management and assessment is performed down to the scale of the component micro-stocks so that the basic assumption of 'unit stock' described originally by Gulland (1969) becomes at least vaguely valid.

This paper documents an approach to increasing the resolution of assessment and management to the scale (100 – 1,000s m) appropriate to the management of the black-lip abalone (*Haliotis rubra*) stocks of western Victoria, Australia. It provides a

rarely documented example of the sustainability issues confronting the world's fisheries.

Abalone Fisheries Ecology

Abalone are a valuable herbivorous mollusc found on shallow coastal reefs around many of the world's coastlines. They are highly prized by Asian markets, but despite large investments in aquaculture, sea ranching and wild stock management global annual production has declined from around 29,000t in 1969 to below 10,000t today (Prince 2004). In the Australian and New Zealand, two of the largest remaining commercial abalone fisheries, serial losses of productive area across all spatial scales (100 m – 100 km) are currently being observed and reported by active divers, although due to averaging across regional scales this remains largely hidden in official assessments. Despite the billions spent since the 1950s on reseeding, aquaculture, and wild stock management there have been no well documented accounts of the broad scale recovery of lost abalone productivity (Prince 2004). Only devastating evidence of how they can be virtually eliminated through large regions of their former along the North American Pacific and Atlantic European Coasts.

Prince (2003, 2004, 2005) has outlined the problematic nature of managing abalone stocks with orthodox regional management strategies. We will only provide a brief summary for the sake of providing the context of this study. Adult movement and larval movements are generally limited to scales of 10s – 1,000s of meters, while abalone growth and their size of maturity is highly variable over local and regional scales. Upon maturing abalone emerge from hidden interstitial spaces within the coastal reefs and join adult feeding and breeding aggregations (Prince *et al.* 1988).

These aggregations are highly visible making it easy for divers to learn their location and effectively target them for collection (Prince 1989).

This fisheries ecology has important implications for the management of abalone fisheries as they are not the single freely mixing "units" of stock assumed by most management and assessment models (Gulland 1969). Instead they are comprised of many (1,000s - 10,000s) relatively independent and variable self-recruiting units, or micro-stocks (Prince 2005).

Currently most of the remaining abalone fisheries are subject to regional forms of management that rely variously on limited entry, regional Total Allowable Catches (TACs) and Legal Minimum Lengths (LML). As described by Prince *et al*. (1998) the problem with current management is that a 'Tragedy of Scale' occurs whereby regional management fails to effectively control exploitation pressure on the component stocks within a regional fishery. The need for more spatially explicit management of abalone fisheries was identified more than a decade ago in reviews by Prince and Shepherd (1992) and McShane (1995). Applied at regional scales TACs are too large to protect component populations, while regional LMLs will only serve their intended purpose on a subset of populations where the LML and fishing pressure fortuitously combine to preserve sufficient breeding stock to maintain recruitment levels.

Biological Principles of Rapid Assessment

The principles behind the rapid assessment of abalone reefs arose from an understanding of the structure of abalone populations developed through the body of Tasmanian research conducted during the 1980s and for which the most relevant facets have been published in Prince *et al.* (1988), Prince (1989), Nash (1992) and Prince (2003). Much of this research was funded by the various forerunners of the Australian Commonwealth Government's Fisheries Research and Development Corporation (FRDC). The utility of applying these principles to visually assessing individual aggregations was first suggested to JP by a commercial abalone diver in the Western Australian Zone 2 fishery for *Haliotis laevigata*, Mr Terry Adams.

Here we will illustrate the principles using data collected by Prince (1989) for populations of blacklip abalone (*H. rubra*) in SE Tasmania, Australia. Other regions and species will have varying ages and sizes of maturity to this population, it is however our belief that the broader life history and morphological patterns described here for *H. rubra* are displayed by most if not all abalone species, and can quite possibly be adapted for many species other than abalone.

Allometric Growth, Maturity, Emergence and Shell Appearance

In figure 1 the comparative age – length relationships for two nearby reefs, George III Rock and Blubber Head, in SE Tasmanian are shown. Note the similar shaped curves with relatively linear juvenile growth slowing at the onset of maturity around 5 years old and approaching asymptotic size and full maturity around 10 years of age. Note the approximately 20mm difference in size at age between these sites throughout the life cycle. Figure 2 shows the same length growth curve for George III Rock population together with the weight at age curve for the George III Rock population.

The age and length of onset and full maturity is also shown. The growth and maturity ogives presented in these figures match are consistent with the wider suite of other Tasmanian abalone populations profiled by Nash (1992). Figure 3 shows the size profile and figure 4 the age profile of emergent abalone in this population.

The length of cryptic juvenile abalone increases relatively linearly up to about 4 years of age (figure 1). This fast growth phase produces a thin flat oval shell shape which is apparently highly vulnerable to predation (Prince *et al.* 1988). This vulnerability presumably forces the juveniles to remain wedged tightly and cryptically in permanently dark interstitial reef spaces where few if any epibiota colonise their shells. This cryptic juvenile phase allows newly emerged maturing abalone to be recognised by their flat clean shells.

As maturing sub-adults (4–8 years old approx.) linear flat growth slows and the abalone switches to growth in shell thickness and meat weight. The sub-adult phase also coincides with a rapid decline in rates of natural mortality, probably because the increasing thickness of their shell makes them less vulnerable to attack (Prince *et al.*1988). It is presumably this relative invulnerability that allows maturing abalone to behave less cryptically and move into adult feeding and breeding aggregations on top of reefs (Prince et al. 1988, Nash 1992). Whatever the explanation, during the process of maturation abalone emerge into the light on top of the reef and from that time a succession of fouling organisms invades the clean surface of the emergent shell, and the successively smaller subsequent annual growth increments. Over several years the shells will take on the appearance of the surrounding reef surfaces and their camouflage will be almost complete (figure 5).

During the maturation period the whirl of the shell deepens its spiral and the abalone shell becomes less oval shaped and more like a round deep bowl substantially increasing its volume while adding less and less length in successive growing seasons.

In a study of the relationship between water movement and shell shape for a range of species from the eastern Pacific, New Zealand and southern Australia, Tissot (1992) showed that shells with raised shell sculpture experienced greater drag than smooth shell species. Results from tank experiments showed that both *H. rubra* and *H. laevigata*, the two main commercially exploited Australian species had relatively lower drag coefficients even in high water velocities when compared with the remainder of the 13 species tested. Broadly speaking, species with raised shell sculptures were those found in habitats subjected to less water movement than those species with smoother shells that tended to occupy more exposed locations. He also suggested that tenacity to resist dislodgement was another important factor affecting horizontal sub-tidal distribution and that shell sculpturing may armour some species against shell crushing predators. It is reasonable to speculate that these principles apply within species to the extent that juveniles and sub adults may differ from mature abalone in terms of their ability to resist dislodgement and predation so that prior to maturity, survival is favoured by a smoother more elongate shell and occupancy of cryptic habitat. In contrast, during adulthood abalone are likely to be capable of clinging more tenaciously to reefs by virtue of a stronger muscular foot that resists shearing forces associated with having a more domed shell shape.

Studies by Tissot (1988) and by Worthington et al. (1995) have also provided evidence supporting the hypothesis that variation in shell morphology is related to growth rate. In the latter study of *H. rubra* populations in NSW, those with slow grow rates had wider shells per unit length than those with faster growth rates. This implies that shells from populations with slow growth rates would tend towards a rounded rather than ovoid shape, consistent with our observations.

Around Tasmania abalone approach the average maximum length, and 100% maturity and emergence around 10 years of age. The average maximum weight (approximately 10% greater) and maximum gonad volume is achieved some 2–3 years later. There is variability in these ages around Tasmania and it appears the length of the life-cycle is several years shorter in warmer waters off Victoria, NSW and SA. In spite of this variability the pattern is conserved — maturity and emergence is largely age related and the same generalised growth and maturity ogives are observed.

Of great relevance in this context is the fact that during the 5–year process of maturation the average weight of each animal increases by more than 400%. Assuming natural survival rates of around 90%, this weight gain in individual abalone during this period counteracts natural attrition to double the biomass (or yield per recruit) and presumably the potential larval production of each age class.

Whatever the underlying reasons for the apparent coincidence between emergence and sexual maturity this phenomenon provides a powerful visual mechanism for rapidly determining the status of an abalone stock and reviewing prevailing LMLs. Observing either a catch, or an emergent abalone population *in situ*, allows one to

immediately gauge the size distribution and appearance of the shell relative to the LML. Following the principles enunciated here, the size of first maturity (and obviously the variability around it) can be gauged by the size of the flat clean oval shaped shells, while the size of full maturity can be judged by the size of individuals with rounded, high shells, fouled with the same epibiota found atop the reef. By using these characteristics as a surrogate for determining maturity, the proportion of sub-adult or fully mature individuals in the catch, or *in situ* population, can be used to gauge the fishing mortality sustained by the population and the level of breeding stock that is preserved.

The Qualitative Analysis of Catch Curves

The age structure of a fished stock has been called a catch curve and its quantitative analysis can be used to derive estimates of natural and fishing mortality (Beverton and Holt 1957, Nash 1992). At its core this Rapid Assessment technique is a qualitative analysis of the size distribution of the abalone population. Of course a crude size distribution must be converted into an age structure before assessments can be made using the principles of catch curve analysis. In the Rapid Assessment approach this is achieved via assumptions, outlined above, that across broad regions abalone are conservative and follow primarily age related maturity and emergence ogives over several years. These assumptions allow the size distribution of shells to be converted qualitatively into an age distribution relative to the age of maturity.

On this basis a sample of shells is examined with regard to;
- The size of first maturity and emergence ascertained by the size of clean flat shelled individuals,

- The size of full maturity gauged from size of individuals with bowl-like shells and fouling like the top of the reef, and

- The overall size distribution of the sample relative to the size of first maturity, full maturity and the LML.

In the analysis of this visual information two useful supporting observations that can be made by abalone divers and solicited during industry-based assessments are:

1. The proportion of emergent abalone being left behind because they are smaller than the LML, and

2. The appearance of abalone shell at legal minimum sizes (flat, oval and clean, or high, rounded and fouled).

The logical catch curve Decision Tree that is then used to analyse these observations is illustrated below, firstly for a depleted population and then for a lightly exploited stock.

Populations at risk of severe depletion due to high exploitation rates are comprised principally of recently emerged maturing sub-adults. These individuals all tend to have clean flat shells because they have been emergent for a short time period that is insufficient for colonisation by fouling epibiota. The fishery will remove them from the reef before they have a chance to develop adult levels of fecundity and contribute substantially to recruitment. Divers will observe relatively few abalone being left below the LML in these populations. This is because the size of maturity and emergence in these populations is either close to or larger than the LML and protects insignificant levels of breeding biomass.

In contrast, lightly exploited populations are comprised of many fully mature adult year classes. These year classes are recognised by the bowl-like shape of the shells and the mature fouling epibiotic assemblages on their shells that give them an appearance similar to their reef top habitat. Clean flat shelled individuals tend to be rare in samples from these populations, and *in situ* will only be found hidden at the back of ledges and caves. Relatively unfished abalone populations typically contain numerous rounded bowl-like shells with heavy fouling that are substantially above the LML simply because fishing pressure (F) is low.

Qualitative Validation

Since first being alerted to the idea of visually assessing abalone populations, one of us (JP) has spent 12 summers participating in New Zealand's commercial free-diving fishery for *Haliotis iris* and this has provided an opportunity for extensive qualitative verification of this technique. During this period JP has dived as a member of a long standing dive team that have consistently landed approximately 30% of the annual catch from Fiordland (PAUA 5A) on the south-western coast of the South Island. The long term members of that dive team have kept detailed personal logbooks describing their last 20 years of diving and these logs document trends for the specific locations they have revisited consistently during that time. These circumstances made it possible to become familiar with the appearance of a sub-sample of populations throughout the region together with a qualitative impression of population trajectories over the last decade, and to place this within the context of localized population trends over the last two decades.

The observations that can be drawn from this body of experience to verify the utility of the Rapid Assessment approach are that;

1. Unfished or lightly fished populations all have (or had) high, round and fouled shells, although in areas where considerable sand blasting occurs the fouling will be in the form of borer impact and erosion, rather than epibiotic growth.

2. Reefs produce several generations of clean, flat, oval shells before severe declines.

3. In heavily depleted areas the only abalone beds that persist were formerly classed as stunted patches. When stunted populations are subject to legal fishing pressure (only abalone above the LML are taken) large numbers of high rounded and fouled shell individuals will still be found, although abalone over the legal measure may become virtually non-existent.

4. A further observation from this experience that is relevant to the Decision Tree developed to support the Rapid Assessment technique, and described below, is that the observed declines in abalone abundance have not been adequately, reflected in daily or hourly catch rates. They are more clearly reflected in the length of shoreline that must be covered to maintain daily catch targets and in the increasing frequency with which particular locations must be revisited.

Using the Observations of Commercial Divers

The Rapid Assessment technique allows the capacity of the researcher to be greatly enhanced by interviewing experienced divers. The features used to appraise LMLs; size of emergent abalone, shell shape and extent of epibiotic growth, and how they vary spatially within the fishing grounds are learned empirically by divers who depend on these observations to fish efficiently. With the supportive input of the divers a qualitative map of 100's of km of abalone carrying shoreline can be rapidly

assembled over the course of 5–10 days. Once the abalone grounds have been mapped then relatively few days of research diving and shell sampling can be used to ground truth and calibrate the anecdotal accounts so that concrete recommendations about reforming LMLs and catch levels can be developed.

Diver Education

As well as using these techniques as part of a researcher's tool kit, we have found that when these principles are converted into succinct simple language they provide a highly effective means of educating abalone divers and empowering them through education to meaningfully engage in the process of developing micro-management.

Taught as simple precepts the principles can be encapsulated as follows;

- Clean shell abalone have only recently emerged to join the adult breeding and feeding aggregations and have contributed few eggs and larvae to the population.
- Abalone should only be harvested when their shells have become fouled, rounded and high because this will allow for a 200% gain in weight and several years of adult egg production prior to harvest.
- Abalone should not be collected as juveniles and sub-adults while their shells are relatively clean of fouling growth, and while their shells are still growing with a flat oval shape.
- Minimum lengths should be set for each reef to ensure these aims are achieved.

Reef Assessment Decision Tree

As described below the application of these techniques in the Western Zone of Victorian led to a demand to apply these principles within an open decision making process through which quota owners and divers could jointly assess and discuss management of individual reefs within their zone. To this end the Rapid Assessment principles have been incorporated into a focus group framework we call Reef Assessment Workshops. The discussion during these workshops needs to be structured, disciplined and transparent if they are to generate agreed assessments of reefs and develop the corporate resolve necessary to make and implement difficult management decisions. For this purpose we developed a Decision Tree using elements of the technique to place each reef area into one of eight categories. This Decision Tree was discussed and agreed upon by the members of WADA during their initial reef assessment workshop prior to its application. An important part of this process was that each assessed category of reef also had an associated pre-agreed management strategy.

The first level of assessment shown by the Decision Tree (figure 6) is made on the basis of long term (5–15 year) trends in the catch and effort statistics for each reef code. In Victoria these reef codes are approximately 1–10 km segments of coastline for which basic catch and effort statistics have been collected since 1979. By extrapolating from a cruder level of data aggregation catch and effort trends can be extrapolated back to the mid–1960s. Where possible we also like to have available spatially explicit shell size composition in the catch. Electronically acquired data for each area are now being progressively collected by the commercial divers and through government research surveys.

Although it may be desirable, access to data of this quality is not essential in applying the Decision Tree. In our experience groups of divers have sufficient shared knowledge of their resource and its history that they can qualitatively respond to these aspects of the Decision Tree without access to statistics or size composition data.

Traditionally catch rates are used extensively in fisheries assessments to provide indices of abundance. This is accepted as being highly problematic for abalone and invertebrates generally (Oresanz and Jamieson 1998; Prince and Hilborn 1998) and in common with many species (Winters and Wheeler 1985) the catchability of abalone probably increases exponentially with declining stock abundance (Prince 1992). The principle reasons for this are:

1. Catch rate data are aggregated over too many abalone aggregations to be meaningful and short duration searches that yield poor catches are irretrievably concealed within reported catch and effort data.

2. The visual nature of abalone diving and the high level of knowledge that divers have about the location and abundance at each location enables them to accurately allocate diving time to differing aggregations in direct proportion to the amount of abalone in each aggregation.

3. There is evidence that blacklip abalone re-aggregate after fishing so that although the total abundance and number of aggregations reduces, the density of abalone within aggregations is at least partially restored.

The effect of this is to keep effort and catch proportional to each other which means that catch rates remain extremely stable even as a resource is depleted. This direct relationship between catch and effort renders CPUE useless as an index of abundance, but the underlying mechanism causing the relationship – the high level of knowledge

divers have about the abundance of abalone each area - also provides an assessment opportunity.

Within the Reef Assessment Workshops effort and catch are both assumed to be indicators of stock abundance in a specific location unless there are coherent reasons for the contrary. Some locations are inherently unattractive for diving insofar as they can be remote, expensive and difficult to access; or because they present normally poor or dangerous diving conditions. These exceptions to the indicator assumptions can contain under-utilized abalone beds. During our initial reef assessment, where relevant these aspects of each reef were documented prior to proceeding further along the Decision Tree phase of the Rapid Assessment process.

Thus the first order evaluation within the Decision Tree is; are catch and effort levels stable (remaining around the same level) or are they unstable (rising or falling over time)? Our interest here is not in year to year variability but longer term trends i.e. is the average for the last five years similar to the average of 5–10 years ago, and 10–15 years ago.

<u>Unstable Catch and Effort Trends</u>

If we decide that catch and effort trends are unstable for a reef code the second order assessment is; is catch and effort rising or falling?

Where catch and effort continues to decline over some period of years it will inevitably be found that the shells are almost entirely clean flat oval shells because the fishery is almost entirely reliant on heavily exploiting the sub-adult abalone as they

begin maturing and as soon as they emerge onto the reef surface (Category 2). This category of reef is recruitment overfished and this drives the decline in catch and effort. The immediate priority for these areas should be to stabilize and rebuild levels of breeding stock by increasing LMLs and/or reducing catches. Cost intensive interventions such as reseeding and translocation are unlikely to be economically viable in these areas because of the existence of considerable natural breeding potential.

Where catch and effort are rising two possible explanations arise. In a limited entry fishery rising catch and effort on a reef is of more general concern because it indicates that effort is being displaced from elsewhere for some reason. This intensified fishing pressure on the reef being assessed is likely to eventually destabilize an otherwise stable stock (Category 4). Where the catch is principally of high, rounded shells with a good cover of fouling the rising trend may be sustainable. However, no increase can be sustained indefinitely and given that lightly exploited abalone reefs in any contemporary abalone fishery are few, this indicator is normally a warning sign for decline in abundance. Where the size of shells is decreasing and flat clean shells are heavily represented in the catch, pre-emptive responses should be considered to prevent further increases in fishing pressure. This can be achieved by increasing LMLs and/or reducing catches. Again cost-intensive interventions such as reseeding and translocation are unlikely to be cost-effective in these areas because considerable residual breeding stocks already exist.

Catch and effort will also rise when a management strategy aimed at rebuilding stock levels begins to have a positive impact (Category 5). These are areas that will have

previously been rated as either Category 1–4 and been the subject of a previous conservative management decision. The unstable trend of rising catch and effort in this case is an indication that the previous management decision is working and breeding stocks and production is increasing. The improving status should be confirmed by an increasing shell size in the catch and an increased proportion of high, rounded and fouled shells. Divers should also be observing an increasing distribution of abalone across the reef surface. No further management action is required in these situations.

Stable Catch and Effort Trends

Where catch and effort trends are judged to be stable over time; the question to ask is whether it is stable at a high or low level? Is the area stable and productive, or stable but unproductive? Where the judgment is that an area is stable but unproductive, historic accounts and data together with observations of the quantity and appearance of abalone can be used to distinguish locations that were once productive (Category 1), from areas that have never been productive (Category 8).

Every abalone fishery has areas that were productive in the early history of the fishery but were rapidly depleted and failed to recover (Category 1). Anecdotal information from retired divers who fished during the early years of the fishery, historic data and the nature of the shell from these locations can be used to diagnose their status. These areas often had a particularly large size of maturity, were close to home ports, or in relatively sheltered, or shallow water. For these reasons early fishing pressure focused intensively on these locations causing rapid depletion of local brood stocks and consequent recruitment collapses. If still producing any abalone, the shell from these

areas will be clean and flat at a size considerably above the LML, indicating the population is mostly comprised of large sub-adult abalone. These locations now offer great promise for the long term increases in catch levels if successfully rehabilitated using reef scale management. However, even a low level of continued fishing will prevent any recovery in these areas. This is akin to the predator pit phenomenon where low levels of predation effectively prevent the accumulation of a breeding stock sufficient to support exponential population growth. The immediate aim with these areas should be to provide a long enough respite from fishing to rebuild levels of breeding stock. This could be achieved through closure for some years or imposition of an extremely high LML. Where residual breeding stocks are extremely low or even locally extinct it may prove cost effective to reintroduce breeding stocks with translocations of adults or even reseeding. Once the breeding stock has been rebuilt in these areas and fishing is again considered, thought will need to be given to preventing a recurrence of over-fishing. These reefs will need particular protection through a high LML or a protective Reef Code TAC. The LML or TAC should be set to a level that ensures the catch is principally comprised of shells that are high, rounded and heavily fouled.

Every abalone fishery also has areas that for some reason contain few abalone and have never been productive (Category 8) this might because of lack of suitable habitat, unfavourable environmental conditions, or perhaps because the limited dispersal power of abalone prevented colonization in the first place. These areas need to be distinguished from Categories 1 & 7 through the knowledge of both retired and current divers. In the long term some of these areas might offer scope for enhancing

production, but in the short term it is probably better to focus management effort on areas with proven production potential.

Variations on this latter category are areas of "stunted" or "shorty" abalone (Category 7). To some extent the distinction between Categories 7 and 8 is arbitrary because Category 8 reefs also often contain some low level of stunted stocks. In Category 7 reefs the problem is not so much a lack of abalone but that environmental conditions or density dependence effects do not support growth through to the LML. This category of reef will be unproductive but sustainable because the existing LML preserves a high level of the original breeding biomass. The high level of breeding biomass in these areas will ensure a high level of recruitment from the cryptic habitat in the short to medium term, which will make them robust to fishing pressure for 5–10 years. A regional plan for reef management should be seeking to transfer fishing pressure from categories 1–4 into these areas. Reducing LMLs in these areas can increase the sustainable yield from these areas. In the long term, reef based management should seek to ensure that, like these stunted areas, all reefs possess a substantial mature biomass below their respective LMLs that have not been set so high as to prevent the majority of abalone entering the fishery.

Where the assessment indicates that catch and effort is stable and productive the third order assessment needed is between areas that are actually in slow decline (Category 3) and those that, within the precision of our assessment process can be considered, sustainable (Category 6). Here the nature of the shell can be used to distinguish between the two areas.

Where shells are clean and flat the stock is operating at a low level of potential egg production, and in all likelihood future recruitment rates will decline. Extreme caution should be exercised with these stocks (Category 3) and a close watch maintained. The stability of catch and effort in these areas often masks actual declines that the divers will be seeing. The divers should be questioned about whether the size of aggregations, the area covered by abalone and the size of abalone are declining? In all probability this will be the case, and if management is not improved catch and effort in these areas will also begin to decline after some years. Pro-active management in these areas repays immediate dividends; this should be aimed at stabilizing and rebuilding the level of breeding stock on these reefs. These areas will still have good levels of recruitment and can be expected to stabilize rapidly and rebuild productivity if management is improved. Again increased LMLs and lower catches could be used to achieve this objective. Costly interventions such as reseeding and translocation are unlikely to be cost effective in these areas because considerable residual breeding stocks already exist.

Where catch and effort trends are stable and the abalone in the catch are fouled, round and high (Category 6) management is about as good as it gets and we have grounds for hoping catches from these areas are sustainable. No further management action is required in these situations. However, we must be aware that the system we are using is qualitative and relatively imprecise. The imperfect state of abalone science is such that there can be no guarantees that even the best managed areas are going to prove sustainable on a time scale measured in decades. However, time is on our side with these areas. Nonetheless, if catches are reduced in other areas through management action without reducing the level of a zonal TAC, or increasing access to stunted

stocks (Category 7), then these areas will be forced to take the brunt of transferred fishing pressure. Such scenarios can potentially shift abalone stocks from Category 6 to a less sustainable category; however under these circumstances the Decision Tree process will at least ensure that an associated change in management is recommended.

The Process of Depletion and Rehabilitation

As shown in figure 7 these different reef categories can be considered as forming a gradient of exploited or managed states. From underfished (Category 7) through well managed (Category 6) and recovering (Category 5) to declining (Categories 2–4) and depleted (Category 1) states. Clearly the purpose of reef management is to progress all reefs towards the sustainable productivity typical of Category 6.

Inter-Reef Issues

The discussion so far has largely treated the different Categories of reef as independent units to be managed in isolation of each other. In terms of abalone movement and population parameters this may be the reality. However, within the context of zonal TACs any management action applied to one reef will have flow on impacts on other reefs. This must be recognized and addressed in a coordinated manner. To some extent catch can be transferred into reef categories 6 & 7 (currently well managed and stunted stocks) but particularly in the case of the Category 6 (currently well managed) wise judgment will be required to ensure that transfer of catch does not destabilize these areas. In many cases there will be insufficient capacity to absorb this transferred fishing pressure and Zonal TACs will need to be reduced in the short to medium term to allow rebuilding processes to take place on some reefs without destabilizing others.

A Case Study of the Victorian Western Zone Abalone Fishery

History of Management

During its history of more than four-decades the Victorian abalone fishery has been ostensibly subject to the conventional abalone fisheries management strategies broadly described by Prince and Shepherd (1992). The first measure to be introduced was the limitation of entry to the fishery in 1968 when a limited number of access licence holders were permitted to fish in specific geographic zones. Three management zones each spanning several hundred kilometres of coastline were progressively created and through diver attrition and two for one transferability, introduced during 1984, led to the current allocation of 23 licences in the Eastern Zone, 34 in the Central Zone and 14 in the Western Zone (Fisheries Victoria 2002). Limited entry is considered to be a key reason why fishing has remained sustainable to the present. Subsequently, during the early 1970s minimum shell size limits were implemented as further input controls; two across different regions of the state for *H. rubra* and a third for *H. laevigata*. Outputs were controlled in 1988 with total allowable catch quotas (TACs) that were introduced for each zone. Zonal TACs were equitably divided among the respective access licence holders in each zone, effectively creating Individual Transferable Quotas (ITQs) that could be temporarily traded among licence holders. Unitisation to allow permanent transfer of individual quota units to potential investors who do not hold an abalone fishery access licence is the next management initiative proposed for this fishery (Fisheries Victoria 2005).

Although Victoria's abalone management regime has been relatively constant throughout most of the fishery's history, sophistication in the application of

management strategies has increased in recent times to reflect a shift from subjective to quantitative decision-making and from scales of operation defined by geopolitical boundaries to those more accurately reflecting the interplay between commercial dive fishers and abalone population dynamics.

A decade ago there were no performance indicators to gauge the effectiveness of management strategies applied to the fishery and quantitative links between assessment and management were non-existent. Minimum legal size limits were based on educated guesses rather than scientific estimates to conserve egg production and quotas were set in accordance with average catch histories recorded from catch dockets during preceding years rather than estimates of productive capacity. Although they certainly mitigated potential overfishing, both strategies were applied at large scales encompassing many reefs along hundreds of kilometres of coastline, consequently ignoring the large variation in productivity among reefs within each of the three management zones and having negligible effect in optimising the spread of fishing effort to match differentials in productive capacity.

This ignorance of the need for more spatially explicit management started to change during 1997 with the development of a risk-based mathematical model of the fishery (Gorfine *et al.* 2001) and specific measures of performance that could be used to ensure TAC management strategies remained sustainable (Fisheries Victoria 2002). The importance of spatial scale in defining abalone populations had long been recognised by abalone researchers, however attempts to model the fishery at reef scales were impeded by data insufficiencies (Gorfine and Dixon 2000). Although modelling could be readily applied at the scale of management zones, this meant that

model parameters were potentially biased averages across many different populations. Since then, the chosen assessment model has been substantially refined into a sophisticated software package applied at sub-zonal or regional scales. The Victorian Abalone Fishery Management Plan includes provision for the adoption of finer scales of management but nothing is prescribed beyond reef-scale catch performance indicators based on historical variation in catch. However, modelling at the reef scale remains an unrealistic proposition because of the logistical impediments and prohibitive costs of acquiring sufficient data. Recognition of these modelling limitations provided the impetus to seek alternative methods for quantifying reef scale productivity.

Under the existing Victorian Abalone Fishery Management Plan annual fisheries assessments are conducted through the Abalone Fishery Assessment Group (AbaloneFAG) convened by Primary Industries Research Victoria (PIRVic), the research division of the Department of Primary Industries (DPI). The AbaloneFAG includes participants from all major stakeholder entities. A keystone of the assessment process is the prescribed use of a quantitative fisheries model that estimates the risk for current and alternative levels of catch that current and future abalone biomass is or will be less than specific reference values. The Abalone Fisheries Committee (AFC), a sub-committee of the Fisheries Co-management Council (FCC), is charged with using these results from formal AbaloneFAG workshops to formulate independent advice about future zonal TACs that is communicated via FCC to the Minister for Primary Industries. FCC and its subcommittees are comprised of ministerially appointed members competitively selected on the basis of their specific expertise rather than any stakeholder affiliation. Although FCC advises the Minister on

fisheries matters, Fisheries Victoria is the division within DPI with statutory responsibility for development and delivery of fisheries policy and regulation under the *Fisheries Act 1995*. The Victorian *Fisheries Act 1995* is the only fisheries legislation in Australia that contains provisions for co-management and it is this aspect of the legislation that facilitates stakeholder-driven micro-management initiatives.

The Application of Rapid Assessment in the Western Zone

In August 2001 an inaugural Australian Abalone Convention was held in Adelaide, Australia and the Fisheries Research and Development Corporation (FRDC), one of the convention's co-sponsors invited one of us (JP) to address the convention on future directions for research and management. The material presented forms the basis of Prince (2005). Following that presentation the Victorian Abalone Divers Association (VADA), an association of Victorian Central Zone divers, requested a similar address be presented at their AGM later that year when a number of Western Zone divers were present, including Mr Vin Gannon then the secretary of the Western Abalone Divers Association (WADA). Following the VADA AGM, and at the instigation of Vin Gannon, a meeting of WADA in November, 2001 resolved to engage JP to conduct a rapid appraisal of the existing size limit (LML) that was applied across the Victorian Western Zone.

There are a couple of interesting points to note about the initiation of change in the Western Zone. Firstly, it was primarily the employed divers rather than the quota holding licence owners who initiated action. Secondly, the terms of the initial contract were strictly prescribed by the quota owners who controlled the WADA's purse

strings. Discussions were to be strictly limited to advice about the current LML of 120mm and WADA stipulated that there was to be no discussion about changing catch levels for the Zone.

Between 19 March and 25 March 2002, JP interviewed WADA divers about the reefs they dived and the characteristics of the abalone on each reef, conducted ground-truthing dives with several divers, inspected catches from across the zone, and held two meetings with WADA members during which he initially outlined the principles he was applying, and finally presented his conclusions. A written report documented the principles behind the rapid appraisal technique and his findings were presented to WADA in April 2002 (Prince 2002). The conclusion was that the western end of the Zone, around Portland, being close to a recognized source of upwelling generally had larger size of maturity than the LML of 120mm and was experiencing recruitment overfishing. While the eastern end, around Port Fairy, being more removed from sources of oceanic nutrients, generally matured below the LML and had more stable levels of recruitment.

Based on this advice, during 2002 WADA implemented a small number of voluntary reef code minimum lengths that were larger than the legislated LML. Agreement on this course of action was initially difficult because of the mistrust that divers felt towards each other and their belief that the proposed voluntary actions could not be enforced. However, WADA members eventually embraced the concept that if the majority of divers complied then improved management outcomes would be achieved. One important reef, The Crags, located midway between the two principal ports, proved particularly influential on the future of micro-management in the Zone. This

area was visited frequently by divers from both ends of the Zone and consequently provided the basis for a shared experience with reef scale management. With the exception of this reef there was only minimal overlap between the areas dived from each port and this lack of shared experience tended to be a long-standing source of tension between the two groups of divers. To some extent it was the declining productivity of this important reef code, witnessed by both ports, that was the important catalyst for achieving changes. The initial voluntary increase in the Minimum Length at the Crags apparently achieved a surprisingly rapid reversal of growth overfishing that convinced the divers a micro-management approach was worth pursuing and extending more generally throughout the Zone. This conviction about the process in turn led to improved compliance with the voluntary agreements.

During the second half of 2002, WADA members realised that the increasing complexity of compliance and the extra administration required to maintain an effective association required the appointment of a part-time executive officer. This position was required to reduce the burden on WADA office bearers, who were also full-time divers. In December 2002, Mr Harry Peeters, was appointed as Executive Officer (EO) for the Association. This appointment came only months after Fisheries Victoria appointed Mr Dallas D'Silva to the position of Senior Project Officer (Abalone). Both came from backgrounds independent of the abalone fishery and carried none of the 'baggage' that previous periods of conflict had left among many within both industry and government. The EO of WADA is a retired policeman with experience as a Board member for various governmental organisations, and came with a strong background in people management. He quickly realised that a close co-operative relationship with Fisheries Victoria needed to be established if WADA was

to be able to achieve a workable system of voluntary reef code minimum lengths higher than the existing LMLs. He has also proved adept at having a 'quiet word' with individual divers or quota owners who have at times proved less than enthusiastic about supporting the evolving system of voluntary reef code management regimes and operating within the increasingly complex code of conduct which has been used to enact a range of voluntary agreements made by WADA. In this way the EO has played a pivotal role in enhancing the power of peer group pressure. The Fisheries Victoria manager has also been keen to assist industry to take a more active role in managing the resource, in contrast to the previous 'steady as she goes' attitude adopted by the fisheries agency. His active and creative participation, discussed in more detail below, has been critical in supporting and enhancing the radical changes that have occurred in the Western Zone.

In February 2003, JP facilitated a one-day workshop in Port Fairy to review the voluntary minimum lengths that had been implemented during the previous year. Up until this time the initial terms of engagement which precluded discussion of catch levels had remained in place. At this meeting there was considerable discussion about the unplanned flow of effort around the zone which was occurring in response to the voluntary reef code minimum lengths. These concerns gave rise to agreement that WADA should move to assessing all Reef Codes and developing their ability to manage both catch and reef code minimum lengths.

In September 2003, the first of the annual reef assessment workshops was conducted. This first workshop was held over three days and included a structured learning component entitled, "Developing Environmental Assessment and Management

Decision-making Skills". The course was developed for WADA with the aim of introducing concepts of decision-making matrices and decision rules to divers and owners. Some of the areas covered by the course included:

- Management of localised marine resources

- Reef assessment

- Categorising exploitation histories to assess states of abalone reefs

- Profiling catch and effort histories

- Environmental decision-making matrices.

At the workshop WADA members discussed and agreed both the decision tree they would use for the assessment of each reef code and the appropriate management action for each category of assessed reef. The workshop was attended by virtually all of the divers from the zone and the majority of the 14 licence holders. Also in attendance were representatives of the management (Mr Dallas D'Silva, Fisheries Victoria) and research agencies (Dr Harry Gorfine, abalone researcher and Mr Bruce Taylor, resource modeller from PIRVic.).

Outcomes of the workshop included:

- An initial assessment of each of the 36 reef codes.

- Re-affirmation of the need to plan the distribution of fishing effort across reef codes in the Western Zone.

- Identification of the total allowable catch contribution (referred to as quota reference point – QRP), which could reasonably and responsibly be expected from each reef code for the 2004/05 season.

- Identification of the upper reference point (URP) at which a reef code could be presented as a candidate for detailed evaluation and possible closure for the remainder of the season.

Using the agreed QRPs for each reef code WADA developed its proposal for the TACC for the next season. Following the workshop, WADA indicated to government that it wanted a reduction in TACC from the 275 tonnes in 2003/04 to 254 tonnes for the 2004/05 season. This request conflicted with the advice offered by AFC which on the basis of the zonal assessment model argued for a larger reduction. The WADA argued in its submission that its newly established process should be allowed time to develop and that WADA should not be forced to reduce catches faster than its members decided. This request was subsequently agreed to by government.

Over the 2004/05 season, the new system of reef code quotas operated with considerable success. Some estimates of the catch that would be taken from particular reefs (Categories 2–4) proved to be too conservative, whilst the estimates of how much could be harvested from previously under-exploited reefs (Categories 7 & 8) generally proved over optimistic, but on balance, Reef Code closures were generally made at an appropriate time. Although the closure of some reefs made it more difficult for divers to catch their quota in only one end of the zone, it was well accepted with consequently high compliance.

In October 2004, WADA conducted a second two day reef assessment workshop. This workshop was a more refined version of the first and had the benefit of increased catch data and more focussed diver observations to base decisions upon. It built on the

previous workshop and simply reviewed the previous assessment of each reef code, rather than re-assessing each reef code. An indication of the growing sophistication of the reef scale management process was that despite WADA having considerable difficulty agreeing on reef code minimum lengths at the initial workshop during 2002, at this workshop only two years later the group began generating proposals for multiple minimum lengths within some reef codes based on fine scale maps and codes of conduct. Following the outcomes of the October workshop, at a November meeting of WADA the following motions were adopted:

1. "That the Association adopt a strategy to restore the blacklip resource to a sustainable quota level of 270 tonnes by 2009."

2. "That the Western Zone recommends to the Minister that, in light of our five-year plan, we recommend a TACC of 210 tonnes for the 2005/06 quota year."

This time WADA was forced to argue against the AFC and some dissident members who were arguing that catches should remain higher. Subsequently, the TACC for 2005/06 was set at 221 tonnes. The fact that the Association was able to request such a dramatic reduction of TACC is a reflection of the growing acceptance of both the need and the process of applying micro-management to the Western Zone resource as well as the maturing of WADA as an organisation. The Association members are now fully committed to actively controlling their own destiny by being fully involved in the management of the resource.

In March 2005, WADA made a further improvement to its process by instigating a Catch Planning workshop that followed the announcement of the TAC for the new quota year, but preceded the 1 April opening of the new season. At this meeting

WADA members agreed not to disperse the quota reduction uniformly or haphazardly across their zone. Instead they agreed to act strategically and focus the reduction on areas that they assessed to be most depleted but to have the most potential for being brought back into production with reef scale management. To this end they used the reductions to close or radically reduce the catch in a number Category 1-3 reefs with the aim of re-opening them in 3 years time with substantially higher reef code minimum lengths.

Government Involvement

From the side of the government management and research agencies, Fisheries Victoria (FV) and PIRVic respectively, there have been a number of innovative initiatives that have supported the actions of WADA.

- A system of Memoranda of Understanding (MOU) has been instigated that provides a more flexible approach for monitoring and controlling catch for each reef system. These MOUs, used by both Western and Central Zones, are negotiated with the each Association using the results of Reef Assessment Workshops to usefully document the Association's intended reef management plan for the year. Although less rigid than regulation, the imperative provided by the formal MOU goes some way to empowering WADA's executive officer as he endeavours to enforce peer group pressure on less supportive divers or quota owners.

- Establishment of an Interactive Voice Recording (IVR) system to accurately record the quantity and precise location of diver catches immediately a catch is landed and to monitor diver movements between reefs with differing size limits.

- Progress towards an interactive website linked to the IVR system which will allow divers access to progressive catch figures in real time i.e. each evening or morning prior to diving.

- Development for WADA of a relational database into which WADA's reef code assessment can be entered, and which also contains catch histories, CPUE statistics, fishery independent abundance statistics and independent length frequency statistics from research surveys. This allows WADA to continuously update its assessment, access all the existing data for each reef code and produce a variety of user-friendly reports.

- Participating with WADA members in conducting a research fishing exercise on Julia Bank Reef which has been assessed as a Category 7 (stunted stock). This exercise aimed at quantitatively determining the size of maturity with the view to developing proposals for a lower LML. This initiative included the unique components whereby the participating divers pooled their catches and then distributed them evenly to ensure that the scientific aspect remained the priority during the exercise, and of utilizing local inspection forces as observers aboard each vessel while the divers operated with a 90 mm minimum length considerably below the 120mm LML.

- Increasing access to a remote and previously lightly utilized area has been facilitated by FV, through negotiating with their counterparts in the adjoining state of South Australia and gaining approval for landing into the interstate port of Port MacDonnell. This involved developing inter-jurisdictional arrangements that meet the compliance needs of Victorian and South Australian fisheries officers.

- Participating with WADA members in a number of trials of reseeding of juveniles and translocation of adult abalone into several depleted reefs. These trials have involved the voluntary closure of the reefs for four years, participation of divers in out planting seed abalone and the translocation of adults, and the development of regular monitoring programs to evaluate the success of the venture.

- Fisheries Victoria have also worked creatively within their constraints to support decisions made by WADA members. Although WADA members have generally preferred that their voluntary agreements on reef code minimum lengths would eventually become formalised as regulations, the difficulty of enforcing multiple LMLs within a single zone has caused the agency to regulate a more simplified system of LMLs. However, based on their inspection of catches, fisheries compliance officers have been able to provide the WADA EO with intelligence about those few divers who are not abiding by voluntary agreements, thus supporting the process of peer group pressure. Likewise, when several quota owners who were not members of WADA made noisy protests to the minister in objection to WADA's request for a large zonal TAC reduction they were informed that they had been free to participate in WADA's process and should have availed themselves of this opportunity had they wanted their voices heard.

Concluding Discussion

This paper has described a novel experiment in addressing the sustainability issues confronting spatially complex fisheries. Obviously these initiatives have been in place for an interval of time that is too short to demonstrate a reversal of the downward recruitment trends we believe have been impacting abalone stocks in many areas of

the Western Zone. Abalone populations are inherently variable, a characteristic that may necessitate a level of complexity in our technique which we are not yet equipped to deal with. Furthermore external factors related to human population growth and environmental changes are major threats to fisheries sustainability. To some extent these impacts will inevitably increase and potentially threaten industry's motivation and commitment for reef scale management processes. Nevertheless, rebuilding and maintaining the abundance of fully fecund adults and multiple age classes of breeding stock must at least slow the trends divers believe they are observing. Furthermore, we believe we already have strong qualitative evidence that growth overfishing is being reversed in a number of reefs critical to the Western Zone. In time we hope to calibrate and refine our technique on the basis of the appearance of abalone shells across a range of reefs that have been proven with quantitative catch, effort, size structure and survey data to be sustainable.

Already we believe this example offers important lessons that are generally applicable.

The critical starting point for this experiment has been the acceptance that the task of achieving sustainability in this resource is beyond the resources available within government agencies, and a willingness by industry associations to take it upon themselves to draw upon the collective knowledge of past and present commercial abalone divers and the substantial potential for their members to collect additional data (Gorfine and Dixon 2001). To do this effectively has required the development of a structured learning process to develop and engage industry participants in reef-scale assessments and the industry response to this process has been striking. Combined

with the active and creative support offered by fisheries agency personnel and government employed researchers within industry-led assessment workshops, through developing new government instruments within existing regulations and appropriate technological aids, the process provides a remarkable contrast to the often adversarial relationships exhibited among fisheries resource users and decision-makers (see Symes 1999). The effect of this has been to bring about a cultural change in the way the three organisations interact.

In the context of the recognised need to provide the correct incentive for stakeholders to pursue sustainability (Hilborn et al. 2005) the role of non-quota owning divers in initiating action is of particular interest. The incentive for this group has been purely their interest in maintaining careers and family life styles as they approach mid-life and suggests to us that with the appropriate mix of education and grass root involvement a broader range of incentives can be harnessed to achieve sustainability than may be generally appreciated.

Also of importance to this process has been the 'flagship' role of 'The Crags' reef. This reef is widely used by the Western Zone divers and the first reef code minimum length rapidly reversed the growth overfishing that had evidently been occurring. The effect of this was to galvanize and create enthusiastic support for continuing and extending the process of reef scale management.

The challenge now is to integrate the top down and the bottom up forms of management that are now in place so that they effectively complement each other. In the short term this can be achieved by modelling the effects of different quota levels at

the highest resolution possible, and then using the industry-driven process to semi-quantitatively determine the finer spatial distribution of the chosen catch quotas. However, in the longer term a reef-scale model simulation capability will be necessary to test the outcomes from scenarios developed based on the information generated by industry so that reef-scale catch distributions are optimised.

If fishery sustainability is to be realised over the longer-term the overall process must stand the test of time and not be dependent on the participation of specific individuals. Rewards must be sufficient and timely to ensure that industry participants at all levels from the catching sector remain committed to the process (see Levin 1999). In time this will foster a stewardship culture that will be considered the norm by subsequent generations entering the fishery. If rewards only accrue to owners then incentives for contracted divers to contribute their resource observations will be weak (see Symes 1999).

Acknowledgements

have recently announced their intention to provide substantial long term funding to support extending these concepts into other regions of the Australian abalone fishery.

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